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A SYSTEMATIC REVIEW ON QUANTIFIABLE PHYSICAL RISK FACTORS FOR NON-SPECIFIC ADOLESCENT LOW BACK PAIN

MASTERARBEIT

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1. Scientific Accompanying Text

Introduction:

Back pain begins early in life and its prevalence rises during adolescence, especially around the age of 12-15 [1-3] until the figures equal those of adults by the age of 18 [1, 4]. The risk for back pain in adults is higher if the individual already had previous events of back pain in adolescence and thus the focus of research, prevention and treatment should be shifted to adolescents [5]. Of all the cases of adolescent spinal pain one third is considered non-specific [6] and of these, psychosocial parameters [7-10] and some life style factors [11-14] are already well established as risk factors. On the other hand, physical parameters show a controversial picture which also differs from findings in adults [15-17]. It therefore follows that psychosocial factors dominate the risk factors for back pain in adolescents [18]. Interestingly this is a finding of a recent study which furthermore states that physical factors are underestimated by previous studies [19]. Most studies thus far investigated physical factors by self-report and used uncontrolled, heterogenous samples of school children [3, 16]. Additionally, participants were not subdivided by pain characteristics such as localization, intensity, frequency and duration [21, 22]. Importantly only 10-20% of adolescents with back pain reported frequent pain with high intensity [20] which should be monitored more carefully than the other 80-90% of adolescents.

Hence, the goals of this review are to determine whether there are quantifiable physical risk factors for LBP in adolescents and to investigate whether and how the identified studies provided data on pain characteristics.

Own contribution: My supervisor Brigitte Wirth (BW) had already done the first investigative literature search and written the study proposal when I (TP) entered the project. I helped refining it and wrote the extended introduction based on the study proposal. BW corrected the drafts and improved them as needed.

Methods:

A professional systematic search for studies published before 25 September 2015 was conducted in PubMed, Medline, EMBASE, Cochrane, CINAHL, PEDro and PsycINFO by a professional medical librarian. This search was redone on the 24th of October 2016. The search was not restricted to physical risk factors because they might have been secondary outcomes in other studies. This systematic review belongs to a larger project thus the search was also not restricted to just LBP but to any type of back pain. There were also no limitations for the publication date. MeSH were used as search terms as well as keywords. Cross-sectional, prospective and retrospective English studies on LBP in adolescents aged 10 to 18

were included. It was shown that puberty is a risk factor for back pain [15]. However, they needed to use quantifiable measurements and address explicitly back pain to be included in this systematic review. Specified pathologies (e.g. scoliosis, Scheuermann's disease) and particular populations such as athletes were exclusion criteria. Furthermore, studies that focused on lifestyle factors (obesity, computer use), on musculoskeletal pain in general and pain in the area of the SI joint, on genetic analyses, or only used questionnaires, were also excluded. Study selection was done by two authors (BW and TP). They, in a first step, scanned the titles and abstracts and in a second step search the full texts of the eligible articles. In two consensus meetings disagreements regarding the eligibility of articles were discussed. A third author (Kim Humphreys, KH) was consulted if necessary. In a last step, only studies on LBP were identified. The quality assessment (incl. consensus meetings) was done by two authors. The Cohen's kappa for quantifying the agreement of raters' ratings was calculated with SPSS. The assessment was done with a modified version of the "Critical appraisal form for quantitative studies" by Law et al. [18] with 14 questions for cross-sectional and retrospective studies and 15 questions for prospective studies. The latter included additionally a question on drop-outs. Each question could be answered with "Yes" or "No". A study was of moderate to high quality if it reached 60% or more of the max. score. The data extraction was done by one author (TP) and included study design, number/age/gender of participants, physical risk factors, assessment and tests used, results, conclusions, pain characteristics (location, intensity, frequency and duration).
Own contribution: I helped my supervisor (BW) defining the inclusion and exclusion criteria for the literature search which was done by a professional librarian. The article selection then was done by two authors, TP and BW. The quality appraisal was also done by two authors, BW and Sandra Rosser (SR), a research assistant. I then extracted the data on my own and a fourth author, Kim Humphreys (KH), could be consulted any time if necessary. In the end, I wrote the first draft of this section and BW corrected and completed it in compliance with me.
Results:
Study selection: The data base searches resulted in a total of 6703 articles of which 2224 were duplicates. After screening titles and abstracts, 48 articles were thought to be eligible for this review. After reading full texts, 25 articles were considered suitable. Of these, 3 studies focused only on neck pain so that in the end 22 studies remained in this systematic review. Three studies were prospective, 16 cross-sectional, one retrospective and two consisted of both a cross-sectional and prospective part.

Quality: The two reviewers (BW and SR) agreed on 19 articles. In the remaining three articles [19-21], they disagreed on the clinical importance. Here, the average of both ratings was taken into account. The resulting κ value was 0.84 ($p<0.001$). The mean quality score of the articles was 10.1 ± 2.2 points (range: 5 to 13.5 points). Four cross-sectional and one prospective study were below moderate quality.

Risk factors: Several risk factors could be identified but need further clarification. Five studies reported reduced or both reduced and increased endurance of trunk muscles as a risk factor for LBP in adolescents [19, 21-24]. As for trunk mobility, the results are controversial but an interesting prospective study of high quality investigated lumbar sagittal mobility combined with lumbar extension strength [25]. It found that a high mobility/strength ratio might be a risk factor for LBP. Another clear risk factor was trunk asymmetry which was reported as a risk factor for LBP in adolescents by three studies [26-28]. Decreased hip mobility was found to be a risk factor by two studies [21, 38] and three other studies stated abnormal endurance and strength of the quadriceps and lower limb power to be a risk factor for LBP [22, 23, 29]. Many articles investigated different aspects of anthropometric measurements. They found sitting height and sitting posture just to play a minor role in the context of risk factors for LBP in adolescents [20, 28, 30]. In contrast to this, postural alignment in stance emerged as a risk factor concordantly by three studies, but only in boys [31-33]. In girls, no such association could be found [34].

Pain characteristics: Thirteen studies described pain intensity using either the visual analogue scale (Visual Analog Scale, VAS) [23, 26, 29, 35] or divers indicators like doctors' visit, use of painkillers or interferences with activities [22, 25, 27, 28, 32, 36-39]. The VAS scale showed mild to moderate pain intensity. The percentage of adolescents seeking care ranged from 4% [28] to 16% [37] and using painkillers from 6% [25, 38] to 25% [39]. Fifteen studies investigated pain frequency. Eight of these studies used more than one time frame [22, 26, 28, 32, 33, 36, 37, 39] two studies showed the year prevalence [25, 38] and one study showed month [30], week [35] and point prevalence respectively [27]. Two studies used terms like "never, sometimes/occasionally, often, very often, always" instead of time frames [23, 40]. Just two studies focused on a homogenous group of severe pain patients [21, 24]. The pain duration was described only in 5 studies [22, 25, 27, 29, 38] and only three studies asked for pain in other areas of the body [26, 29, 35].

Own contribution: BW and myself did the analyses together. This time I also analysed the quality assessment results. We had several discussion meetings on what our results are, what findings we should focus on and how we best present our results. Again, I wrote a draft of this section and BW corrected and completed it in compliance with me. Furthermore, I did the diagrams and tables and discussed them with BW.

Discussion:

The comparison of the study results is impeded by the variety of methods and outcomes that were used as well as the heterogeneity of the participants.

Risk factors: One risk factor for adolescent LBP that appeared in this review was reduced back muscle endurance. It was mostly tested using the Biering-Sorensen test. Nevertheless, a recent study just showed that this test has no predictive evidence [41]. Thus, there is a need for standardized prospective studies to investigate the suitability of the Biering-Sorensen test and the role of reduced back muscle endurance in LBP in adolescents. Another risk factor was reduced abdominal muscle endurance. However, as we have no prospective studies in this context no conclusion can be drawn about the causality. In concordance with other reviews [42], it was shown that trunk muscle strength plays only a minor role for LBP in younger populations. An interesting role in this context can be attributed to spinal mobility although there were many divers measurement methods used and results presented. Most of the studies used the finger-to-floor distance or the Schober test to analyse spinal mobility. Again, one study showed that these measurement methods do not predict LBP [41]. But the study which combined strength, or rather endurance, and mobility used a modified Schober test [25]. This might show that the risk for LBP by reduced muscle endurance becomes more accentuated when spinal mobility is enhanced. A clear risk factor is also trunk asymmetry which was tested by forward bending. But a recent study disagrees with these findings [41] and another study states that the forward bending test has just limited positive predictive and sensitive value [43]. Therefore, the application of this test is of minor value for trunk asymmetry. As for the reduced strength of the lower limb, there is no prospective study done yet which means that we cannot conclude about the causality. The situation in terms of hip mobility and hamstring flexibility seems to be more complex because of the diverse methods that were used. A very popular test in this context is the straight leg raise. But as it could be shown, this test is not determined by hamstring elongation, but rather by altered neurodynamics [44, 45]. That is why a positive straight leg raise test shows that rather neural sliding than hamstring tightness might be a risk factor for LBP. Anthropometric measures and sitting posture seem to play just a minor role whereas alignment in stance seems to be more important for the development of LBP. These findings are in concordance with results of other studies in adults [46].

Pain characteristics: Activity restriction or care seeking as proxy measures for pain severity [47] are no valuable measures because some studies could show that in children care seeking is lower than the prevalence of LBP and the impact of LBP on daily life [2, 48]. Furthermore, there is limited agreement between parents' and children's pain reports [49, 50]. Pain intensity is rather associated with pain frequency [51]. For pain frequency, the recall periods should be standardized [52]. Longer periods bear the problem of forgetfulness but might cover more severe episodes. Pain duration was described in just a few studies. However, this characteristic is very important to form homogenous study groups [53].

Limitations: This review was restricted to adolescents aged 10 to 18 which might have excluded interesting findings of slightly older adolescents who are still in development. Furthermore, we excluded physical activity which could have shown fitness-related outcomes to complete the picture. Body build is also an important aspect for some of the risk factors and maybe for LBP itself. Genetic studies might describe the background of the manifestation of body build [39].

Own contribution: As for the results, BW and myself met for several discussion meetings to analyse our findings. Again, I wrote a draft for this section and BW and I corrected and completed it together.

Conclusions:

This review demonstrates a clear need for prospective studies of high quality which investigate the importance of back and abdominal muscle endurance in combination with spina mobility, sagittal postural alignment and neurodynamics. It is recommended for such studies to analyse homogenous groups and to use the VAS scale for quantifying pain intensity rather than proxy measures.

Own contribution: BW and I derived the conclusions together in one of the discussion meetings.

Submission:

BW submitted the paper to the Journal of Pediatric Rehabilitation Medicine on the 28th of February 2017 with the following authors: Tobias Potthoff, MSc, BMed; Sandra Rosser, MSc; Barry K Humphreys, Prof, DC, PhD; Brigitte Wirth, PT, PhD. We received a decision for revision on the 16th of June with the reviewers stating that we put a lot of work in this study and extracted a great amount of data which they found to be presented confusingly. The data presentation should be simplified. BW resubmitted this paper on the 8th of July. The paper was then rejected on the 16th of July because one reviewer still criticized our way of presenting the results whereas another reviewer stated that the text is more coherent now and eligible to publication. After contacting the editor, we are allowed to submit the paper to the same journal again.

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2. Abstract

Purpose: The aim of this systematic review was to analyze the results of studies on quantifiable physical risk factors (beyond questionnaires) for adolescent low back pain (LBP) and to investigate how pain was characterized in these studies.

Methods: A professional systematic search was conducted in Medline (OvidSP), Premedline (PubMed), EMBASE, Cochrane, CINAHL, PEDro and PsycINFO. Cross-sectional, prospective and retrospective English studies on LBP in adolescents aged 10 to 18 were included.

Results: 22 mostly cross-sectional studies were included. Data analysis was impeded by the variety of methods used and by the heterogeneity of the patient samples. Nevertheless, trunk muscle endurance in particular seemed to be associated with adolescent LBP, while a possible association of trunk muscle strength and spinal flexibility was less clear. Pain was inconsistently characterised with only two studies focusing on homogeneous groups of adolescents with more severe LBP.

Conclusion: There is a need for prospective studies on quantifiable physical risk factors for adolescent LBP. Such studies should focus on back and abdominal muscle endurance, possibly in combination with sagittal spinal mobility, sagittal postural alignment and neurodynamics as possible risk factors for LBP. Homogeneous groups in terms of pain characteristics should be included.

Keywords: Adolescent, low back pain, pain characteristics, physical, risk factor, systematic review

3. Introduction

Back pain starts early in life and its prevalence increases with age, accelerating in the early teens around the age of 12 to 15 [1-3] and reaching adult prevalence by the age of 18 [1, 4]. As for low back pain (LBP), an eight-year follow up from adolescence to adulthood showed a fourfold increase in the risk of adolescents with LBP for having LBP in adult life. Thus, it was postulated that the focus of research, prevention and treatment in this area should be changed from the adult to the young population [5].

Although there are several specific pathologies that can result in spinal pain in adolescence, a considerable number of cases of adolescent spinal pain, around one third in a recent study [6], are considered non-specific. As for risk factors for non-specific adolescent LBP, some psychosocial parameters, such as back pain of one or two parents [7, 8] as well as anxiety and depression [7, 9] were identified. Indeed, about 10% of the adolescents with LBP showed an increased probability of having sleep disorders and headaches along with the corresponding psychological problems, possibly linked to a dysregulation of the hypothalamic-pituitary-adrenal axis [10]. As for lifestyle factors, TV consumption, computer use and smoking, but not body weight or fitness level, correlated with LBP [11-14]. With regard to physical parameters, controversial results were found that differed from comparable studies in adults suggesting that risk factors for adult LBP cannot be directly transferred to adolescent LBP [15]. In summary, no physical risk factors for adolescent spinal pain could clearly be defined [11, 16, 17], and it was suggested that psychosocial factors were more important than physical factors for spinal pain in young populations [18]. A recent study, however, found that although psychosomatic symptoms were most strongly associated with 1-month prevalence of adolescent spinal pain, these were followed by factors from the physical and psychosocial domains. Consequently, these authors suggested that the importance of physical risk factors for non-specific adolescent spinal pain may have thus far been underestimated [19]. Furthermore, the majority of studies on adolescent back pain assessed physical risk factors by self-report, using questionnaires [3, 16] and investigated random samples of schoolchildren. However, as the severity of adolescent back pain varies considerably [20], this approach requires a concise characterization of adolescent spinal pain in terms of localization, intensity, frequency and duration [21, 22]. Importantly, the majority of adolescents can be regarded as healthy [10] as they reported that their pain was relatively infrequent and of low intensity [20] and hardly affected their quality of life [23]. Nevertheless, about 10-20% reported frequent pain that was also of higher intensity [20]. In particular, adolescents with frequent pain or pain in more than one spinal area should be carefully monitored as these parameters were linked to sleep disorders [24]. Consequently, a precise characterization of adolescent spinal pain is essential and the investigation of homogeneous populations in terms of pain severity might be informative.

Thus, the goals of this systematic review were to determine whether there are quantifiable physical risk factors for LBP in adolescence and to investigate whether and how the corresponding studies provided data on pain characteristics.

4. Methods

a. Search strategy

A systematic literature search of studies on risk factors for back pain in adolescents up to and including September 25, 2015 in Medline (OvidSP), Premedline (PubMed), EMBASE, Cochrane, CINAHL, PEDro and PsycINFO was performed by a professional medical librarian from the local university library. The search was redone on October 24, 2016 in order to search for new publications. The two resulting publications from this re-search [19, 25] were included in the discussion section, but not in the results. In the first step, the search was not restricted to physical risk factors as studies on psychosocial risk factors might have investigated physical risk factors as secondary outcomes. The literature search was also not restricted to LBP because the present study was part of a larger project that investigated physical risk factors for any type of adolescent back pain. No limits were applied for the publication date of the articles. Medical subheadings (MeSH) were used as search terms. To find the most recently published studies that have not yet been linked with MeSH, keywords were also searched for in the title or abstract. The search strategies can be seen in Appendix A.

b. Inclusion criteria

A study was included in this review if it was a cross-sectional, a retrospective or prospective cohort study in English and investigated back pain in adolescents from age 10 to 18. This age range was chosen because there is some evidence that puberty is a risk factor for back pain in the young [15] with pubertal development starting at 9.5 years for girls and at 10 years for boys [26]. If a study covered a wider age range it was included only if the mean age was within the age limits of this review. In addition, to be included in this review, the studies had to use quantifiable measurements and not be restricted to questionnaires only. Furthermore, studies were excluded if they focused on back pain of a specified pathology (scoliosis, Scheuermann’s disease, spondylolisthesis, disc degeneration, hypermobility, coccydynia, fibromyalgia, posttraumatic or postoperative back pain, radiographic studies), on particular populations (athletes, disabled children) or exclusively on lifestyle factors (computer use, school bag weight, body weight, sport activities). Studies that focused on possible genetic background for adolescent LBP were also excluded. Lastly, only studies that explicitly investigated back pain were included, while studies on the sacro-iliac area or on musculoskeletal pain in general were excluded.

c. *Study selection*

In a first step, titles and abstracts of the articles were screened by two authors (TP and BW) according to the inclusion and exclusion criteria listed above. In a second step, the same two authors screened the full text of the remaining articles for eligibility. The full texts were also retrieved if no abstract was available or the selection could not be made on the basis of the abstract. In two consensus meetings some discrepancies regarding eligibility of the articles were resolved. A third author (KH) was consulted if necessary. In a last step, only studies that focused on LBP were selected for the present review.

d. *Quality assessment*

Quality assessment was performed by two authors (SR and BW) and a consensus meeting was held after individual ratings to clarify possible disagreements. For quantifying the agreement of the raters' ratings, the Cohen's kappa was calculated using IBM SPSS Statistics 21. The quality assessment was based on the "Critical appraisal form for quantitative studies" by Law et al. [27]. Because no intervention was applied, the questions referring to any intervention were removed as done in a comparable review [28] and in their place question 14 (estimates of random variability of data) was added from the checklist by Downs and Black [29]. Moreover, two questions on biases [28] and on the adequate description of the assessments [28, 29] were included (questions 4 and 7, Appendix B). All questions were either answered by YES (= 1 point) or NO (=0 point) except from the question on biases where the scoring was reversed. As the question addressing drop-outs was only applicable to prospective studies, the total quality score was maximally 14 points for cross-sectional and retrospective studies and 15 points for prospective studies. The assessment form is shown in Appendix B. According to the guidelines by the Physiotherapy Evidence Database (PEDro), a study was regarded as being of moderate to high quality if it reached at least 60% of the maximum score [30], which was 8.5 points for cross-sectional and retrospective studies and 9 points for prospective studies.

e. Data extraction

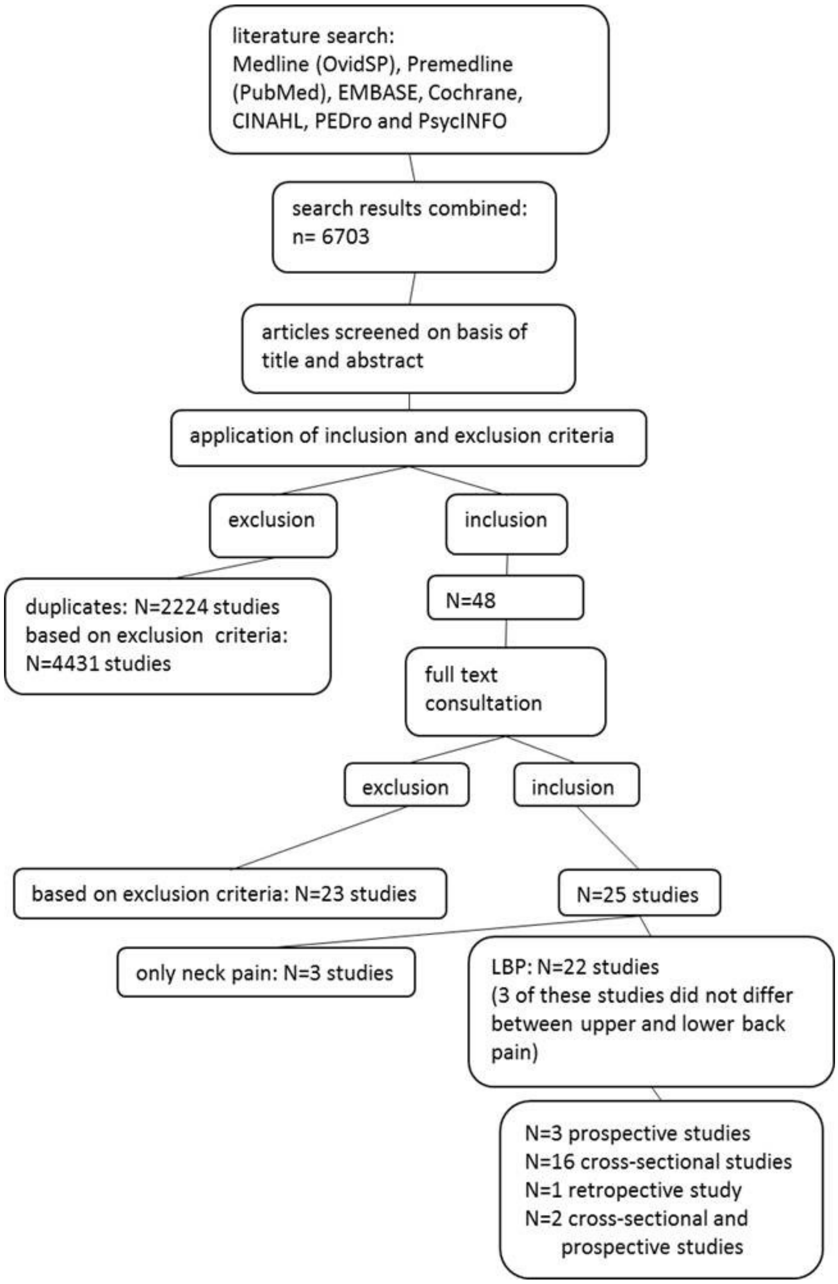
One author (TP) extracted the following information from each article: study design, number, age and gender of participants, physical risk factors that were investigated, assessments and tests that were used, results as well as pain characteristics of the participants (pain severity, pain frequency, pain duration, further pain areas reported).

5. Results

a. Study selection

The selection process is illustrated in figure 1. The database searches resulted in a total of 6703 articles of which 2224 were duplicates. After screening the titles and abstracts for the inclusion and exclusion criteria, 48 articles were considered potentially suitable for this review. After reading the full texts, 25 studies remained that fulfilled the inclusion and exclusion criteria. In a last step, three studies that solely focused on neck pain were excluded. This resulted in 22 studies identified as suitable for this review. Three studies were prospective, 16 cross-sectional and one study was retrospective. Two studies consisted of both a cross-sectional and a prospective part. Three of the 22 studies [31-33] investigated 'back pain' and did not differentiate between lower and upper back, while the remaining focused explicitly on LBP.

Figure 1: Flow diagram of the study selection process.



b. Quality of the selected studies

After the consensus meeting, the two reviewers agreed on the scores of 19 articles. In 3 articles [34-36], there was a difference of one point in the item covering the report of clinical importance of the study results, which was accepted and the average of both ratings was used for further analysis. The resulting κ value was 0.84 ($p<0.001$). The mean quality score of all 22 studies was 10.1 ± 2.2 points (range: 5 to 13.5 points). The mean quality score for the prospective studies (including the two studies with a prospective and a cross-sectional part) was 10.6 ± 1.8 (range: 8 to 13 points) out of 15 points and 10.0 ± 2.3 (range: 5 to 13.5 points) out of 14 points for the cross-sectional (including the retrospective) studies, respectively. Four cross-sectional studies and one prospective study were below moderate quality according to the guidelines by PEDro.

c. Quantifiable physical risk factors

The results for all outcome variables are shown in detail in table 1 and summarized per outcome variable in table 2.

i. Trunk

There was concordant evidence from several cross-sectional studies that reduced endurance of trunk extensor muscles [37-39] as well as of trunk flexor muscles [36, 39] was associated with LBP. This finding was slightly challenged by one study that found both, reduced and greater abdominal and back muscle endurance in girls with LBP [33] and one low-quality study that found no association between abdominal muscle endurance and adolescent LBP [38]. The evidence for trunk strength was conflicting with two studies that investigated different aspects of trunk strength and found controversial results [31, 40]. As for trunk mobility, there was evidence from one prospective study that sagittal range of motion (ROM) might be associated with adolescent LBP. They found that unresisted sagittal ROM as measured in a triaxial trunk dynamometer was lower in the group that did not complain about LBP at baseline and at 2 years follow-up ('never LBP') and in the group that newly developed LBP ('new LBP') [40]. In contrast, when measuring either spinal mobility in flexion or extension, the results were conflicting with several studies using different clinical tests and finding markedly controversial results [22, 36, 39-42]. Interestingly, high lumbar sagittal mobility combined with low lumbar extension strength (high mobility/strength ratio) emerged as a risk factor for LBP from one prospective study of high quality [42]. With regard to functional trunk stability, the results were controversial. One low-quality cross-sectional study found that trunk stability was a risk factor for adolescent LBP [43], whereas it did not emerge as a risk factor from another investigation [22]. Trunk asymmetry, in contrast, was consistently reported to be a risk factor for LBP in three studies, one of which was cross-sectional [22], one retrospective [8] and one prospective [44].

Table 1: Characteristics of the studies included and their outcome variables.

Author, year	Title	Study design	Participants: Number (m/f) Age	Outcome variables	Main results	Quality score
Astfalck et al., 2010 [37]	A detailed characterization of pain, disability, physical and psychological features of a small group of adolescents with non-specific chronic low back pain	Cross-sectional	N=56 (28/28) 15.4±0.5/15.7±0.5 years (with LBP/without LBP)	Sitting posture (trunk angle/lumbar angle) Trunk extensor endurance (Biering Sorensen test) Thigh muscle endurance (squat)	Significant difference between LBP patients and controls in back muscle endurance and squat endurance	13
Astfalck et al., 2010 [34]	Sitting postures and trunk muscle activity in adolescents with and without nonspecific chronic low back pain.	Cross-sectional	N=56 (28/28) 15.4±0.5/15.7±0.5 years (with LBP/without LBP)	Subclassification by O'Sullivan (based on video) Sitting posture: comparison of spinal angles, pelvic angles, back and abdominal muscle activity (EMG) in usual and slump sitting position	Without subgrouping: no significant differences in sitting posture (usual and slump sitting) between adolescents with and without LBP. After subgrouping: lower activation of the internal oblique muscle in usual sitting position in the LBP group.	13.5
Balague et al., 2010 [40]	The association between isoinertial trunk muscle performance and low back pain in male adolescents.	Cross sectional and prospective over 2 years	N=95 (95/0) 14.0±1.7 years Prospective: 11 drop-outs	Unresisted range of motion in the three anatomic axes Isometric and isoinertial trunk strength in flexion, extension, lateral flexion and rotation Fingertip-floor distance Schober test Beighton hypermobility score	Cross-sectional study: No association between trunk performance and LBP Prospective study: 'Persistent' LBP group: reduced trunk mobility (higher fingertip-floor distance) than the other groups 'Never LBP' and 'new LBP' group: lower baseline sagittal ROM than the other groups No association between isoinertial trunk performance and LBP	11
Bernard et al., 2007 [38]	Muscle assessment in healthy teenagers Comparison with teenagers with low back pain.	Cross-sectional	N=51 (11/40) LBP patients, N=276 (154/122) controls 14.6±1.7 years	Back muscle endurance (Biering Sorensen test) Abdominal muscle endurance (Shirado's test) Quadriceps endurance (Killy's test) Hip extensor endurance Fingertip-floor distance Heel-cheek distance	Significantly lower endurance of back muscles, quadriceps and hip extensors in adolescents with LBP. No difference in trunk flexor endurance.	<60%/8.5
Burton et al., 1996 [41]	The natural history of low back pain in adolescents.	Prospective over 5 years	N=216 (approximately 50%/50%) 11.7 years	Lumbar sagittal flexibility (Flexicurve)	Mean flexion mobility significantly decreased in girls. No significant relationship between LBP and sagittal mobility	<60%/9.0
Cudre et al., 2006 [43]	Relationship between impaired functional stability and back pain in children: an exploratory cross-sectional study	Cross-sectional	N=125 (57/68) Median age = 10 years	Functional stability (Matthiass Test using a new scoring system)	Significant association between Matthiass test and LBP in the last week (OR 1.77,1.08 to 2.91) No association between Matthiass test and upper back pain in the last week.	<60%/8.5
Dolphens et al., 2012 [48]	Sagittal standing posture and its association with spinal pain.	Cross-sectional	N=1196 (639/557) Boys: 12.6±0.5 years Girls: 10.6±0.5 years	Global sagittal alignment (pelvic displacement, trunk lean angle, body lean angle) and local spinopelvic parameters (e.g. number of vertebrae in the lumbar lordosis, vertebral level of apex, pelvic orientation in the sagittal plane) in habitual standing using digital images, inclinometry and accelerometry.	Significant association between LBP lifetime prevalence and pelvic displacement in boys. No association between local spinopelvic parameters and LBP.	12

Dolphens et al., 2013 [49]	Classification system of the normal variation in sagittal standing plane alignment. A study among adolescent boys.	Cross-sectional	N=639 (639/0) 12.6±0.5 years	Global sagittal alignment (pelvic displacement, trunk lean angle, body lean angle) and local spinopelvic parameters (e.g. number of vertebrae in the lumbar lordosis, vertebral level of apex, pelvic orientation in the sagittal plane) in habitual standing using digital images, inclinometry and accelerometry.	Cluster analysis: 3 clusters of global alignment: neutral, sway-back, leaning-forward. Significantly higher LBP lifetime and month prevalence in boys with sway-back posture. No association between local spinopelvic parameters and LBP.	11
Dolphens et al., 2014 [50]	Classification system of the sagittal standing alignment in young adolescent girls	Cross-sectional	N=557 (0/557) 10.6±0.5 years	Global sagittal alignment (pelvic displacement, trunk lean angle, body lean angle) and local spinopelvic parameters (e.g. number of vertebrae in the lumbar lordosis, vertebral level of apex, pelvic orientation in the sagittal plane) in habitual standing using digital images, inclinometry and accelerometry.	3 postural subtypes, comparable to boys. No association between posture clusters and spinal pain measures.	9
Ebrall, 1994 [35]	Some anthropometric dimensions of male adolescents with idiopathic low back pain.	Cross-sectional	N=125 (125/0) (38 controls)	13 anthropometric dimensions (e.g. standing height, sitting height, pelvic height, suprapelvic height, trunk length, leg length)	Significantly greater trunk length, sitting height, suprapelvic height and pelvic height in adolescents with LBP.	8.5
Harreby et al., 1999 [45]	Risk factors for low back pain in a cohort of 1389 Danish school children: an epidemiologic study	Cross-sectional	N=1389 (671/718) 13 to 16 years	Tightness of hamstrings (knee extension deficit when hip in 90º flexion)	No association of hamstring tightness and LBP, not even in a subgroup of adolescents with severe LBP	<60%/8.5
Jones et al., 2005 [36]	Biological risk indicators for recurrent non-specific low back pain in adolescents.	Cross-sectional	N=56 28 with recurrent LBP (15/13) 14.9±0.7 years 28 matched controls (15/13) 14.9±0.7 years	Lumbar flexion mobility (modified Schober test) Lateral flexion (side bending) Hip range of motion in flexion (knee extended) Abdominal muscle endurance (sit up test) Sit and reach test	Lumbar sagittal mobility, lumbar mobility in lateral flexion and endurance of abdominal muscles significantly reduced in adolescents with recurrent LBP No association between hip flexion mobility and recurrent LBP.	10.5
Kaspiris et al., 2010 [8]	Non-specific low back pain during childhood. A retrospective epidemiological study of risk factors.	Retrospective	N=692 7.5 to 14 years	Coexisting orthopedic disorders (trunk asymmetry, kyphosis, lordosis, leg-length discrepancy, platypodia, valgus knee)	Significant correlation between LBP and coexisting pediatric orthopedic conditions (no information per each condition given)	<60%/8.5
Merati et al., 2004 [31]	Trunk muscular strength in pre-pubertal children with and without back pain.	Cross-sectional	N=144 (77/67) 11.9±0.3 years	Isometric trunk extensor and flexor muscle strength Isokinetic trunk extensor and flexor muscle strength	Peak torque flexor/ Peak torque extensor ratio higher in boys with back pain at 90°/s angular velocity Authors conclusions: Isometric and isokinetic trunk muscle strength of little importance in back pain occurrence in children	12
Nissinen et al., 1994 [44]	Anthropometric measurements and the incidence of low back pain in a cohort of pubertal children.	Prospective over 2 years	N=859 (451/408) 11.8 years at baseline	Sagittal spine profile (spinal pantograph) Leg-length inequality Sitting height Trunk asymmetry (forward bending test)	Significant association between sitting height, trunk asymmetry and LBP incidence Authors conclusions: Role of anthropometric measures modest.	10
O'Sullivan et al., 2011 [32]	Association of biopsychosocial factors with degree of slump in sitting posture and self-report of back pain in adolescents: a cross-sectional study.	Cross-sectional	N=1596 14.1±0.2 years	Normal sagittal sitting posture (lateral photographs) Back muscle endurance (Biering Sorensen test)	Weak positive association between LBP made worse by sitting and higher degree of slump position Weak negative association between LBP not made worse by sitting and higher degree of slump position	11

Perry et al., 2009 [33]	Fitness, motor competence and body composition are weakly associated with adolescent back pain.	Cross-sectional	N=1608 (825/783) 14.1±0.2 years	Back muscle endurance (sustained back extension test) Abdominal muscle endurance (abdominal curls) Limb muscle performance (standing long jump) Hamstrings flexibility (unilateral sit and reach test) Motor competence (McCarron Assessment of neuromuscular development)	Boys: Positive association between both, reduced and enhanced flexibility and a diagnosis of LBP. Girls: Positive association between greater abdominal endurance and LBP in the last month. Positive association between both, reduced and enhanced back muscle endurance and a diagnosis of LBP. Authors conclusions: Small contribution of these factors to logistic regression models.	13
Salminen, et al., 1992 [39]	Spinal mobility and trunk muscle strength in 15-year-old schoolchildren with and without low-back pain.	Cross-sectional	N=38 (17/21) with recurrent or continual LBP N=38 asymptomatic controls 15 years	Lumbar flexion and extension (flexicurve, Schober test) Fingertip to floor distance Lumbar sagittal mobility (side bending) Flexibility of hip flexor muscles and hamstrings (passive straight leg raise test) Dynamic strength and endurance of abdominal muscles (curl-up test) Endurance of back muscles (Biering Sorensen test)	Adolescents with recurrent/continuous LBP: Decreased lumbar extension mobility, decreased hamstrings flexibility, increased flexion mobility (measured by Schober test, not significant when measured with flexicurve), reduced endurance of abdominal and back muscles.	9
Sjölie and Ljunggren, 2001 [42]	The significance of high lumbar mobility and low lumbar strength for current and future low back pain in adolescents.	Cross-sectional and prospective over one year	N=88 (50/38) 14.7±0.6 years Prospective: N=86	Lumbar flexion and extension mobility (modified Schober test) Lumbar extension strength (modification of the Biering Sorensen test),	Cross-sectional and prospective: LBP associated with low lumbar extension strength and high lumbar mobility-extension strength ratio (high lumbar mobility=sum of flexion and extension mobility, low extension strength) Associations significant for the whole group and for the girls, but not for the boys.	13
Sjölie, 2004 [46]	Low-back pain in adolescents is associated with poor hip mobility and high body mass index.	Cross-sectional	N=88 (50/38) 14.7±0.6 years	Hip mobility (active abduction, flexion, extension, internal and external rotation), Flexibility of hamstrings (active knee extension test)	Significant association of reduced hip flexion, internal rotation and hamstrings flexibility with LBP in boys	10
Smith et al., 2008 [47]	Classification of sagittal thoraco-lumbo-pelvic alignment of the adolescent spine in standing and its relationship to low back pain.	Prospective over 3 years	N=766 14.0±0.2 years	Sagittal thoraco-lumbo-pelvic alignment (lateral standing photographs), 3 angles: Sway angle (C7-Trochanter-Malleolus lat.) Lumbar angle (Trochanter-SIAS-Th12) Trunk angle (Trochanter-Th12-C7)	Adolescents with non-neutral postures: higher odds for all measures of back pain (7 of 15 analyses significant)	11
Wirth et al., 2013 [22]	Spine Day 2012: spinal pain in Swiss school children - epidemiology and risk factors	Cross-sectional	N=434 (211/223) 10.4±2.8 years	Trunk stability (Matthiass test) Trunk asymmetry (forward bending test) Spinal mobililty (fingertip-floor distance) Coordination (single leg stance)	Trunk asymmetry increased odds for LBP	9

LBP=low back pain; N=number; SIAS=spina iliaca anterior superior

Table 2: Summary of the results per outcome variable.
Prospective studies are shown in bold.

Outcome variable	Changes in adolescents with LBP	No changes in adolescents with LBP
Trunk		
Endurance of trunk extensors	Reduced in recurrent/continuous LBP [39] Reduced in LBP [37, 38] Reduced/enhanced in girls with LBP [33]	
Endurance of trunk flexors	Reduced in recurrent/continuous LBP [36, 39] Reduced/enhanced in girls with LBP [33]	[38]
Trunk strength (isometric, isokinetic, isoinertial)	Increased isokinetic flexion/extension ratio in boys with back pain [31]	No change in isometric and isoinertial strength in flexion/extension, lateralflexion, rotation [40]
Spinal mobility in flexion	Reduced flexion and lateral flexion mobility in LBP [36] **Reduced trunk flexion mobility in 'persistent' LBP [40]** Increased flexion mobility in recurrent LBP [39]	[22, 41, **42**]
Spinal mobility in extension	Reduced extension in recurrent/continuous LBP [39]	[41, **42**]
Spinal mobility, sagittal ROM	**Reduced in 'never' and 'new' LBP [40]**	
Mobility/strength ratio	**Low extension strength and high sagittal mobility (increased mobility/strength ratio) in LBP [42]**	
Functional stability (Matthias test)	Reduced in LBP [43]	[22]
Trunk asymmetry (forward bending)	Associated with LBP [8, 22, **44**]	
Lower limb		
Hip range of motion	Decreased hip flexion with extended knee in recurrent LBP [36] Decreased hip flexion and internal rotation in boys [46]	
Hip extensors	Weakness in LBP [38]	
Lower limb strength	Quadriceps weakness in LBP [38] Reduced squat endurance in LBP [37] Reduced limb power in girls with LBP [33]	
Hamstring flexibility	Reduced flexibility in recurrent/continuous LBP [39] Reduced flexibility in boys with LBP [46] Reduced/enhanced flexibility in boys with LBP [33]	No change in severe LBP [45]
Anthropometric measures and posture		
Anthropometric measures	Greater sitting height, pelvic height, suprapelvic height in LBP [35] **Sitting height positively associated with LBP incidence [44]**	
Sitting posture	Weak positive association between greater slump degree and LBP [32]	Decreased thoracic kyphosis and increased lumbar lordosis in LBP only when adolescents were subclassified [34]
Standing posture, global alignment	**Non-neutral posture higher odds for LBP [47]** Increased pelvic displacement angle and sway back posture in boys [48, 49]	No association in girls [50]
Local spinopelvic parameters		No change in vertebral level of the lumbar apex, pelvic tilt, sacral inclination [48]
Other		
Motor competence		No association between neuromuscular development and LBP [33]

LBP=low back pain; ROM=range of motion

ii. Lower limb

Although measured via different outcome measures, there was evidence from two studies that lower limb endurance was associated with LBP [37, 38], which was supported by a third study that found an association between lower limb power and LBP in girls [33]. Despite of one low-quality cross-sectional study that found no association between hamstrings flexibility and severe LBP [45], there was evidence from three studies that changes in hamstrings flexibility might be associated with (more severe) LBP [39], particularly in boys [33, 46], where both, reduced [33, 46] and enhanced [33] flexibility was associated with LBP. As for the hip, one cross-sectional study presented decreased hip flexion (with knee extended) as a risk factor for recurrent LBP [36], while another cross-sectional study reported that decreased hip flexion and internal rotation were associated with LBP, but only in boys [46]. Furthermore, hip extensor weakness was found to be a risk factor, but only in one low quality cross-sectional study [38].

iii. Anthropometric measures and posture

Sitting height emerged as a risk factor for adolescent LBP from one cross-sectional [35] and one prospective [44] study, although its importance was minor [44]. As for sitting posture, only a weak association between greater slump degree and LBP was found in one cross-sectional study [32], while another study found differences in sitting posture only when the adolescents were subclassified [34]. Posture alignment in stance was concordantly stated to be a risk factor for LBP by three studies: Non-neutral alignment emerged from one prospective study [47] and an increased pelvic displacement angle [48] and sway back posture [49] from two cross-sectional studies as risk factors for LBP in adolescence for boys, while a similar study found no such relation in girls [50] . Furthermore, no association of local spinopelvic parameters, such as vertebral level of the lumbar apex, pelvic tilt or sacral inclination [48], and of general motor competence, assessed by a test for neuromuscular development [33], with adolescent LBP were found.

d. Pain characteristics (Table 3)

Pain intensity

Thirteen of the 22 studies described pain intensity of the adolescents. Four studies used the VAS scale and showed that adolescent LBP was on average of mild to moderate intensity [22, 37, 38, 43]. Nine studies used doctors visit, and/or use of painkillers and/or interference with activities as an indicator for pain intensity [8, 33, 40-42, 44-46, 48]. Interpretation of these data was difficult as some studies presented each of these categories separately, while others combined them in different ways. However, the percentage of adolescents who sought medical advice ranged from 4% [44] to 16% [41] and the percentage of adolescents who used painkillers from 6% [42, 46] to 13% [45]. Nine studies did not describe pain severity of the adolescents who they included in their investigations [31, 32, 34-36, 39, 47, 49, 50].

Pain frequency

Eight studies presented prevalence values of more than one time frame, e.g. lifetime and month prevalence [22, 33, 40, 41, 44, 45, 48, 49]. Two studies used solely year prevalence [42, 46], one study reported only month prevalence [32], another study week prevalence [43] and the retrospective study reported point prevalence only [8]. Furthermore, two studies used descriptive terms such as “never, sometimes/occasionally, often, very often, always” to quantify pain frequency [31, 38]. Again, this inconsistency of reporting makes interpretation difficult, even more as five studies did not describe pain frequency of the involved adolescents at all [34, 35, 37, 47, 50]. Interestingly, only two studies explicitly focused on a more homogeneous group of adolescents with either recurrent [36] or recurrent/continuous [39] pain.

Pain duration and pain in other areas

Pain duration was described in five studies [8, 33, 37, 42, 46] and only three studies [22, 37, 43] investigated whether the adolescents with LBP also suffered from pain in other areas of the spine. While one study reported that 64% of the adolescents with LBP also complained about pain in the thoracic spine [37], this percentage was only 26% in another study [43]. A third study reported that the percentage of adolescents with pain in more than one spinal area was higher in girls than in boys, increased with age and reached 57.6% between 13 and 16 years of age [22].

Table 3: Description of pain characteristics.

Author, year	Pain severity	Pain frequency	Pain duration	Further pain area
Astfalck et al., 2010 [37]	Moderate (VAS 4.4 ± 1.9)	x	26.6 ± 12 months	Thoracic spinal pain in 18/28 (64.3%)
Astfalck et al., 2010 [34]	x	x	x	x
Balague et al., 2010 [40]	'Releveant/consequential' LBP (medical attention, interference with activities or both): Baseline: 34.7% (14.7% medical attention, 29.5% interfering with activity) During two-years-follow-up: 17.6%	Last episode of 'relevant/consequential' LBP: Within last week: 15.6% 1-4 weeks ago: 31.3% 1-3 months ago: 25.0% 3-12 months ago: 28.1%	x	x
Bernard et al., 2007 [38]	VAS = 57.5% ±17.2% (median= 60%)	Never, sometimes: 83% Often, very often, always: 17%	x	x
Burton et al., 1996 [41]	Treatment: 15.6%	Lifetime prevalence: Increase from 11.6% at age 11 to 50.4% at age 15 Point prevalence: 3.2% (age 11), 3.9% (age 12), 6.4% (age 13), 10% (age 14), 12.9% (age 15) Recurrent back pain increased from 44% at age 11 to 59% at age 15	x	x
Cudre et al., 2006 [43]	VAS: LBP= 2.5 ± 3.0, Upper back pain= 3.3 ± 3.0	Week prevalence: Upper back pain: 22.6% (28/124), LBP: 17.7% (22/123), Both: 25.8% (33/128)	x	33/128 (25.8%) upper and lower back pain
Dolphens et al., 2012 [48]	Doctor visit: Boys 3.3%, girls 5.4%	Life time prevalence: Boys 28.5%, girls 24% Month prevalence: Boys 13.8%, girls 9.6%	x	x
Dolphens et al., 2013 [49]	x	Life time prevalence: Boys 28.5%, girls 24% Month prevalence: Boys 13.8%, girls 9.6%	x	x
Dolphens et al., 2014 [50]	x	x	x	x
Ebrall, 1994 [35]	x	x	x	x
Harreby et al., 1999 [45]	Use of analgesics: 13.1% Contact with health system: Physician: 15.5% Radiography: 7.6% Physiotherapy: 6.5% Chiropractic: 4.8% Reduced activities: 8.9% Stopped activities: 4.2% Severe LBP: 19.4%	Lifetime/year/month/week/point prevalence: Boys: 49.8%/49.3%/24.7%/12.5%/4.3% Girls: 67.4%/52.1%/36.1%/15.2%/6.1%	x	x
Jones et al., 2005 [36]	x	Recurrent (=repeated acute episodes)	x	x

Kaspiris et al., 2010 [8]	Radiating leg pain: 5.88% Moderate or severe restriction of activity: 19.61%/23.52% (depending on questionnaire) Medical advice/analgesics: 23.53%	Point prevalence: 22.1% (boys 18.9%, girls 25.2%)	<1day: 90.2% 2 days to 1 week: 8.5% > 7 days: 1.3%	x
Merati et al., 2004 [31]	x	Occasionally, often, very often in last 6 months: 51% (boys 42.9%, girls 59.7%)	x	x
Nissinen et al., 1994 [44]	Doctor visit: 4.4%	One year incidence: 17.6% (boys 16.9%, girls 18.4%) >year ago: 17.6% <year ago: 26.8% In the last month: 55.6%	x	x
O'Sullivan et al., 2011 [32]	x	Month prevalence: 27.6% (male 25.4%, female 29.9%)	x	x
Perry et al., 2009 [33]	Diagnosed back pain: 11.4%	Lifetime prevalence: 46% Month prevalence: 28.1%	> 3 months: 11.3%	x
Salminen, et al., 1992 [39]	x	Recurrent/continuous	x	x
Sjölie and Ljunggren, 2001 [42]	Painkillers in preceding year: 6% Professional treatment in preceding year: 7%	One year prevalence: 57%	1 to 30 days: 41% 31 days to daily: 16%	x
Sjölie, 2004 [46]	Painkillers in preceding year: 6% Professional treatment in preceding year: 7%	One year prevalence: 57% Recurrent (>7 days/year): Boys 24%, Girls 40%	1 to 7 days: 26% 8 to 30 days: 15% >30 days: 9% Daily: 7%	x
Smith et al., 2008 [47]	x	x	x	x
Wirth et al., 2013 [22]	VAS: Age 6-9: 3.7 ±1.9 Age 10-12: 3.9 ±1.9 Age 13-16: 4.5 ±1.8	Lifetime prevalence (age 6-9/10-12/13-16): Boys: 7.1%/9.2%/18.6%; Girls: 5.7%/16.6%/24.1% Once a week (age 6-9/10-12/13-16): 38.4%/46.0%/44.0% Repeatedly a week (age 6-9/10-12/13-16): 15.2%/17.5%/18.7% Daily (age 6-9/10-12/13-16): 4.0%/7.1%/9.0%	x	Multiple pain areas in the spine (age 6-9/10-12/13-16): Boys: 9.0%/19.2%/20.6% Girls: 10.2%/19.9%/37.0%

LBP=low back pain; VAS=visual analogue scale; x=no data

6. Discussion

The aim of this systematic review was to summarize the current knowledge about quantifiable physical risk factors for LBP in adolescence and to investigate how the corresponding studies provided data on pain characteristics. Twenty-two studies were found that matched the inclusion criteria. The vast majority of the studies (N=16) followed a cross-sectional study design, while only three studies were prospective. One study was retrospective and two investigations consisted of a cross-sectional and a prospective part. Mean study quality was around 70% of the maximum score with 5 studies not reaching the level for moderate quality according to the guidelines by PEDro. However, although there were several studies dealing with the topic of quantitative physical risk factors for LBP in adolescents as reported in previous reviews [51, 52], the comparison of results was impeded by the variety of methods and outcomes that were used as well as by the heterogeneity of the participants that were investigated. Only two studies explicitly focused on adolescents who suffered from more severe LBP.

a. *Quantifiable physical risk factors*

There is wide consensus in the literature that psychosocial factors are associated with LBP in adolescents [10, 18, 53, 54]. The role of mechanical factors was reported to be minor, although many studies restricted mechanical factors to body weight, school bag weight or physical activity [18]. However, there is some evidence that the importance of physical risk factors might have been underestimated so far as this domain contributes unique information that is not covered by the other domains [19]. Indeed, this review revealed that there is conclusive evidence that some quantifiable physical parameters might put adolescents at risk for LBP. This accounts particularly for back muscle endurance, which was in this review, in line with a recent review by Lardon [52], concordantly reduced in adolescents with LBP. There was the exception of one study that reported both reduced and enhanced back muscle endurance to be associated with LBP, but only in girls [33]. This study reported, however, small associations of all investigated factors to LBP and was in addition the only one that did not use the Biering-Sorensen test as assessment for back muscle endurance. However, recently, after the systematic literature search for this review was conducted, a prospective study over 2 years on 1300 adolescents between 11 and 15 years reported that none of the common clinical tests, including the Biering-Sorensen test, could predict LBP [25]. This study dichotomized the test results with the lower quartile being defined as a positive test result, and standardization might, according to the authors, have been deficient. This might have influenced the results and thus, a well standardized prospective study in this field is needed. Similarly, reduced endurance of the abdominal muscles was, with the exception of one low-quality study, associated with LBP in three cross-sectional studies, two of which focused on adolescents with recurrent or continuous LBP. However, as no prospective study was found in this context, no conclusion about causality can be drawn. The relevance of trunk muscle strength became less clear. Only one cross-sectional study found some association between LBP and the ratio of flexion and extension peak torque, but only in boys [31]. Thus, in accordance with the findings by the review of Lardon et al. [52], who reported no association between back muscle strength and adolescent LBP, the measurement of trunk muscle strength seems to be of minor importance. Accordingly, the results with regard to spinal mobility were rather diverse as were the measurement methods that were used (Schober test, fingertip-floor distance, flexicurve). In the recent prospective study by Aartun [25], both methods, the fingertip-floor distance as well as the Schober test (with dichotomized results), could not predict future LBP. Interestingly, one prospective study of high quality reported a combined measure of strength and mobility, more precisely a high lumbar mobility-extension strength ratio to be predictive for adolescent LBP [42]. However, in fact, the authors conducted a modification of the Sorensen test, which means that the proposed measure is rather a combination of back muscle endurance and spinal mobility. Thus, it might be hypothesized that the decrease in back muscle endurance is a risk for adolescent LBP, which becomes more accentuated when spinal mobility is enhanced. The results of the study by Salminen et al. [39] might further support this hypothesis as they found decreased endurance of back muscles and abdominal muscles and increased flexion mobility in the adolescents with recurrent/continuous LBP, but unfortunately, they did not combine these measures. Trunk asymmetry, assessed by forward bending, was consistently associated with LBP in this review, but did not have a predictive value in the study by Aartun et al. [25]. This test is broadly used in scoliosis screening, but was reported even in this context to have limited positive predictive and sensitivity values [55]. Thus, its application in the field on non-specific adolescent LBP seems of minor value.

Lower limb performance emerged from three cross-sectional studies consistently as being associated with LBP. Accordingly, knee extensor strength was significantly smaller in adult runners with chronic LBP when compared to control runners [56]. Furthermore, adult patients with chronic LBP who reported psychologic distress and a high pain level showed reduced quadriceps muscle torque probably as a result of increased inhibition of muscle activity [57]. Given these findings, a prospective study in adolescents that includes quadriceps strength might be of interest. The situation in terms of hip mobility and hamstrings flexibility seems more complex as the measuring methods differed substantially. Jones et al. [36] tested hip flexion with the knee extended, which is comparable to the passive straight leg test used by Salminen et al. [39] for assessing hamstrings flexibility. Both studies dealt with a subpopulation of adolescents with more severe LBP and found a positive association between reduced flexibility and recurrent LBP. However, it was shown via ultrasonography that the straight leg raise score is not determined by hamstring elongation [58], but rather by altered neurodynamics such as sliding capacity of the nerve roots and the spinal cord in the thoracolumbar region [59]. Thus, it might rather be impaired neural sliding than hamstrings tightness that could be a risk factor for adolescent LBP. The presumably limited importance of hamstrings flexibility is underlined in the present review by the fact that the two studies by Sjölie et al. [46] and Harreby et al. [45] that measured hamstrings flexibility via knee extension deficit in 90 degrees of hip flexion found contradicting results. Furthermore, the use of sit-and-reach tests for assessing hamstrings flexibility as done in the study by Perry et al. was not recommended [60] or only with reservations [61].

Anthropometric measures and sitting posture seem to play at most a minor role in the context of adolescent LBP, while alignment in stance seems more important. In the prospective study by Smith et al. [47], any deviation from the neutral posture (sway, flat, hyperlordotic) was a risk for back pain. The three cross-sectional studies by Dolphens et al. [48-50] reported sway-back posture to be associated with LBP in boys, while the investigated local spinopelvic parameters, such as apex of lumbar lordosis and pelvic orientation in the sagittal plane did not show a relationship. In contrast, in a recent study of this group, higher lumbar lordotic apex and an increase in pelvis retroversion were the two physical factors with the highest odds for LBP [19]. This corresponds well with findings in adults with chronic LBP, where a greater proportion of patients with a low sacral slope and a long but small lumbar lordosis were reported when compared to healthy controls [62].

b. Pain characteristics

The majority of studies described pain severity via activity restriction or care seeking behaviour, which are seen as proxy measures for severity [21]. Indeed, high pain intensity and activity limitation were reported to be the main factors for care seeking in children and adolescents [54]. However, several studies reported that in children, care seeking is much lower than LBP prevalence and its impact on daily life [2, 63]. The fact that this gap is smaller in older children might be because the pain becomes more bothersome or parents take the issue more seriously [2]. In any case, limited agreement between parents' and children's pain reports was reported in several studies [64, 65]. This agreement increases if pain becomes more intense [65], but still, this discrepancy and the unquantifiable influence of parents on the decision of care-seeking questions the use of care seeking as a measure for pain severity in children and adolescents. Instead, pain intensity seems to be strongly associated with pain frequency [66]. Pain frequency was described via a variety of recall periods. This is in line with a former review [67], but impedes comparison between studies and thus needs to be standardized in future studies. Longer recall periods coincide with a higher level of forgetfulness, but might instead cover more severe episodes as those are remembered more than the less severe [67]. Furthermore, the vast majority of studies did not describe pain duration of their participants, which is a criticism that was also raised by a study focusing on conservative interventions in adolescent LBP [68]. The same applies for further pain areas, which were assessed only in three of the 22 studies. However, this information could be of importance as progression of pain from one to more locations was reported in a prospective study over two years [66] and were associated with sleep disorders [22]. Interestingly, although about 10 to 20% of the adolescents (depending on age) report frequent pain [66, 69] only two studies were found in this review that focused on physical parameters in adolescents with recurrent LBP. Nevertheless, particularly when determining risk factors, heterogeneous patient groups might neutralize potential findings and thus more homogeneous subgroups of adolescents with severe LBP should be studied as persistent adolescent musculoskeletal pain is a risk for chronic pain in adulthood [54].

c. Limitations

Narrowing this review to quantifiable physical risk factors of course led to some limitations. By limiting the age of the adolescents from 10 to 18 years, we might have missed some interesting studies on slightly older adolescents. Indeed, a recent prospective study in adolescents aged 19 years at baseline studied proprioceptive control using muscle vibration and found that an ankle-steered control strategy was a risk factor for developing recurrent mild LBP [70]. Furthermore, we excluded studies on physical activity as this was mostly asked via questionnaires. However, some studies measured aerobic capacity as did the study by Perry et al. This study reported an association between greater aerobic capacity and LBP in the last month [33]. Such an association however disappeared when the model was adjusted for back muscle endurance [71]. Thus, a recent review hypothesized that the aerobic capacity could be a proxy measure for back muscle endurance and both measures could be two manifestations of body build with a genetic background [52]. Indeed, the exclusion of genetic studies is another limitation of the present review. Although there are not many such studies, they focus, in a broader sense, also on quantifiable physical risk factors. For example, Skouen et al. found in 1004 adolescents that genetic variants in an adrenergic candidate gene (beta-2 adrenergic receptor) were associated with chronic comorbid neck and low back pain [72]. This might further support the hypothesis of a dysregulated hypothalamic-pituitary-adrenal axis being involved in chronic pain in adolescents [10].

7. Conclusions

This review demonstrated a clear need for prospective high-quality studies in the field of physical risk factors for adolescent LBP. Based on the results of this study, it is recommended that future studies investigate back and abdominal muscle endurance, possibly in combination with sagittal spinal mobility, sagittal postural alignment and neurodynamics as possible risk factors for the development of LBP in adolescence. It is further recommended that such studies investigate homogeneous groups in terms of pain severity that are clearly characterized for pain frequency, pain duration and additional pain localization other than LBP. Finally, it is recommended that visual analogue scales rather than proxy measures such as medical care-seeking for quantifying pain intensity are used in future studies.

8. Conflict of interest

The authors declare no conflict of interest.

9. References

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10. Appendix

Appendix A: Search strategies.

Medline (OvidSP):

(exp Back Pain/ OR (backache OR dorsalgia OR lumbago OR lumbalgesia OR lumbalgia).ab,ti. OR ((back OR discogenic OR lowback OR loin OR lumbal OR lumbosacral OR lumbosacroiliac OR vertebrogenic) ADJ3 (pain OR ache OR syndrome)).ab,ti.) OR (exp Neck Pain/ OR (cervicalgia* OR cervicodynia* OR neckache*).ab,ti. OR ((neck OR cervical) ADJ3 (pain OR ache)).ab,ti.)

AND

(adolescent/ or (child/ not child, preschool/) OR (juvenile OR adolesc* OR teenage* OR schoolchild* OR child* OR young).ab,ti.)

AND

(Forecasting/ OR risk factors/ OR (risk OR predict* OR indic* OR caus* OR prognos* OR determin* OR forecast*).ab,ti.)

AND

(exp case-control studies/ or exp cohort studies/ or exp cross-sectional studies/ OR exp "review"/ OR (prospectiv* OR retrospectiv* OR followup OR follow-up OR incidence OR longitudinal OR case-control OR cross-sectional OR cohort OR systematic OR review).ab,ti.)

NOT ([adult]/lim OR [middle aged]/lim OR [aged]/lim OR [very elderly]/lim NOT ([school]/lim OR [adolescent]/lim OR [young adult]/lim))

NOT (animals NOT humans).sh.

('adolescent'/exp OR 'schoolchild'/exp OR (juvenile OR adolesc* OR teenage* OR schoolchild* OR child* OR 'young adult' OR 'young adults').ab,ti.)

'prediction'/exp AND 'risk factor'/exp

Premedline (PubMed):

(backache[tiab] OR dorsalgia[tiab] OR lumbago[tiab] OR lumbalgesia[tiab] OR lumbalgia[tiab] OR ((back[tiab] OR discogenic[tiab] OR lowback[tiab] OR loin[tiab] OR lumbal[tiab] OR lumbosacral[tiab] OR lumbosacroiliac[tiab] OR vertebrogenic[tiab]) AND (pain[tiab] OR ache[tiab] OR syndrome[tiab])) OR (cervicalgia[tiab] OR cervicodynia[tiab] OR neckache[tiab] OR ((neck[tiab] OR cervical[tiab]) AND (pain[tiab] OR ache[tiab]))

AND

(juvenile[tiab] OR adolescent[tiab] OR adolescents[tiab] OR teenager[tiab] OR teenage[tiab] OR schoolchild[tiab] OR schoolchildren[tiab] OR child[tiab] OR children[tiab] OR young[tiab])

AND

(risk[tiab] OR prediction[tiab] OR predicting[tiab] OR indication[tiab] OR indicating[tiab] OR cause[tiab] OR causes[tiab] OR causing[tiab] OR prognoses[tiab] OR prognostic[tiab] OR prognosis[tiab] OR determination[tiab] OR determining[tiab] OR forecast[tiab] OR forecasting[tiab] OR forecasts[tiab])

AND

(prospective[tiab] OR retrospective[tiab] OR followup[tiab] OR follow-up[tiab] OR incidence[tiab] OR longitudinal[tiab] OR case-control[tiab] OR cross-sectional[tiab] OR cohort[tiab] OR systematic[tiab] OR review[tiab])

AND

(((inprocess[sb])) OR (publisher[sb] NOT pubstatusnihms NOT pubstatuspmcsd NOT pmcbook))

EMBASE :

('backache'/exp OR (backache OR dorsalgia OR lumbago OR lumbalgesia OR lumbalgia):ab,ti OR ((back OR discogenic OR lowback OR loin OR lumbal OR lumbosacral OR lumbosacroiliac OR vertebrogenic) NEAR/3 (pain OR ache OR syndrome)):ab,ti) OR ('neck pain'/exp OR (cervicalgia* OR cervicodynia* OR neckache*):ab,ti OR ((neck OR cervical) NEAR/3 (pain OR ache)):ab,ti)

AND

('adolescent'/exp OR 'schoolchild'/exp OR (juvenile OR adolesc* OR teenage* OR schoolchild* OR child* OR young):ab,ti)

AND

('prediction and forecasting'/exp OR 'risk factor'/exp OR (risk OR predict* OR indic* OR caus* OR prognos* OR determin* OR forecast*):ab,ti)

AND

('cohort analysis'/exp OR 'cross-sectional study'/exp OR 'longitudinal study'/exp OR 'case control study'/exp OR 'prospective study'/exp OR 'retrospective study'/exp OR 'review'/exp OR 'follow up'/exp OR (prospectiv* OR retrospectiv* OR followup OR follow-up OR incidence OR longitudinal OR case-control OR corss-sectional OR cohort OR systematic OR review):ab,ti)

NOT ([adult]/lim OR [middle aged]/lim OR [aged]/lim OR [very elderly]/lim NOT ([school]/lim OR [adolescent]/lim OR [young adult]/lim))

('adolescent'/exp OR 'schoolchild'/exp OR (juvenile OR adolesc* OR teenage* OR schoolchild* OR child* OR 'young adult' OR 'young adults'):ab,ti)

'prediction'/exp AND 'risk factor'/exp

Cochrane :

(backache OR dorsalgia OR lumbago OR lumbalgesia OR lumbalgia)

((back OR discogenic OR lowback OR loin OR lumbal OR lumbosacral OR lumbosacroiliac OR vertebrogenic) NEAR/3 (pain OR ache OR syndrome))

(cervicalgia* OR cervicodynia* OR neckache*) OR

((neck OR cervical) NEAR/3 (pain OR ache))

AND

(juvenile OR adolesc* OR teenage* OR schoolchild* OR child* OR young)

AND

(risk OR predict* OR indic* OR caus* OR prognos* OR determin* OR forecast*)

AND

(prospectiv* OR retrospectiv* OR followup OR follow-up OR incidence OR longitudinal OR case-control OR corss-sectional OR cohort OR systematic OR review)

CINAHL :

((MH "Back Pain+") OR (TI backache OR dorsalgia OR lumbago OR lumbalgesia OR lumbalgia) OR (AB backache OR dorsalgia OR lumbago OR lumbalgesia OR lumbalgia) OR (TI (back OR discogenic OR lowback OR loin OR lumbal OR lumbosacral OR lumbosacroiliac OR vertebrogenic) N3 (pain OR ache OR syndrome)) OR (AB (back OR discogenic OR lowback OR loin OR lumbal OR lumbosacral OR lumbosacroiliac OR vertebrogenic) N3 (pain OR ache OR syndrome))) OR ((MH "Neck Pain") OR (TI cervicalgia* OR cervicodynia* OR neckache*) OR (AB cervicalgia* OR cervicodynia* OR neckache*) OR (TI (neck OR cervical) N3 (pain OR ache)) OR (AB (neck OR cervical) N3 (pain OR ache)))

AND

((MH "Adolescence+") OR (MH "Child") OR (TI juvenile OR adolesc* OR teenage* OR schoolchild* OR child* OR young) OR (AB juvenile OR adolesc* OR teenage* OR schoolchild* OR child* OR young))

AND

((MH "Risk Factors") OR (TI risk OR predict* OR indic* OR caus* OR prognos* OR determin* OR forecast*) OR (AB risk OR predict* OR indic* OR caus* OR prognos* OR determin* OR forecast*))

AND

((MH "Case Control Studies+") OR (MH "Cross Sectional Studies") OR (MH "Prospective Studies+") OR (MH "Systematic Review") OR (TI prospectiv* OR retrospectiv* OR followup OR follow-up OR incidence OR longitudinal OR case-control OR cross-sectional OR cohort OR systematic OR review) OR (AB prospectiv* OR retrospectiv* OR followup OR follow-up OR incidence OR longitudinal OR case-control OR cross-sectional OR cohort OR systematic OR review))

PEDro:

Back pain adolescen* 14 records

Back pain child*	47 records
Neck pain adolescen*	19 records
Neck pain child*	36 records
Pooled	96 records

PsycINFO :

((DE "Back Pain") OR (TI backache OR dorsalgia OR lumbago OR lumbalgesia OR lumbalgia) OR (AB backache OR dorsalgia OR lumbago OR lumbalgesia OR lumbalgia) OR (TI (back OR discogenic OR lowback OR loin OR lumbal OR lumbosacral OR lumbosacroiliac OR vertebrogenic) N3 (pain OR ache OR syndrome)) OR (AB (back OR discogenic OR lowback OR loin OR lumbal OR lumbosacral OR lumbosacroiliac OR vertebrogenic) N3 (pain OR ache OR syndrome))) OR (((DE "Neck (Anatomy)") AND (DE "Pain")) OR (TI cervicalgia* OR cervicodynia* OR neckache*) OR (AB cervicalgia* OR cervicodynia* OR neckache*) OR (TI (neck OR cervical) N3 (pain OR ache)) OR (AB (neck OR cervical) N3 (pain OR ache)))

AND

(DE "Junior High School Students") OR (DE "Elementary School Students") OR (DE "High School Students") OR (AG Adolescence OR child) OR (TI juvenile OR adolesc* OR teenage* OR schoolchild* OR child* OR young) OR (AB juvenile OR adolesc* OR teenage* OR schoolchild* OR child* OR young)

AND

((((DE "Risk Factors") OR (DE "Causality")) OR (DE "Etiology")) AND (DE "Prediction" OR DE "Prognosis") OR (TI risk OR predict* OR indic* OR caus* OR prognos* OR determin* OR forecast*) OR (AB risk OR predict* OR indic* OR caus* OR prognos* OR determin* OR forecast*))

AND

((DE "Cohort Analysis") OR (DE "Literature Review") OR (DE "Retrospective Studies") OR (DE "Longitudinal Studies") OR DE ("Prospective Studies") OR (DE "Followup Studies") OR (TI prospectiv* OR retrospectiv* OR followup OR follow-up OR incidence OR longitudinal OR case-control OR cross-sectional OR cohort OR systematic OR review) OR (AB prospectiv* OR retrospectiv* OR followup OR follow-up OR incidence OR longitudinal OR case-control OR cross-sectional OR cohort OR systematic OR review))

Appendix B: Quality assessment form.

Adapted from the “Critical appraisal form for quantitative studies” by Law et al [27] using the checklist by Downs and Black [29] and the form by Prins et al. [28]:

CITATION	Provide the full citation for this article in APA format:
STUDY PURPOSE 1: Was the purpose stated clearly? ☐ Yes ☐ No	Outline the purpose of the study. How does the study apply to your research question?
LITERATURE 2: Was relevant background literature reviewed? ☐ Yes ☐ No	Describe the justification of the need for this study:
DESIGN 3: Was the design appropriate for the study question? (e.g., for knowledge level about this issue, outcomes, ethical issues, etc.): ☐ Yes ☐ No 4. Were there any biases (random/nonsystematic error or measurement bias/systematic error) that may have influenced the results (apart from reliability and validity of the outcomes)? ☐ Yes (=0) ☐ No (=1)	Study design: ☐ Randomized (RCT) ☐ prospective cohort ☐ single case design ☐ before and after ☐ case-control ☐ cross-sectional ☐ case study ☐ other Specify any biases that may have been operating and the direction of their influence on the results:
SAMPLE N = Age (range, mean): 5. Was the sample described in detail? ☐ Yes ☐ No 6. Was sample size justified? ☐ Yes ☐ No ☐ N/A	Sampling (who; characteristics; how many; how was sampling done?) If more than one group, was there similarity between the groups?: Describe ethics procedures. Was informed consent obtained?:

<table>
<tr><td rowspan="2">OUTCOMES
7. Were the methods of outcome measurement described sufficiently?
☐ Yes
☐ No</td><td colspan="2">Specify the frequency of outcome measurement (i.e., pre, post, follow-up):</td></tr>
<tr><td>Outcome areas:</td><td>List measures used.:</td></tr>
</table>

8. Were the outcome measures reliable? ☐ Yes ☐ No ☐ Not addressed 9. Were the outcome measures valid? ☐ Yes ☐ No ☐ Not addressed		
RESULTS 10. Results were reported in terms of statistical significance? ☐ Yes ☐ No ☐ N/A ☐ Not addressed 11. Were the analysis method(s) appropriate? ☐ Yes ☐ No ☐ Not addressed	What were the results? Were they statistically significant (i.e., $p < 0.05$)? If not statistically significant, was study big enough to show an important difference if it should occur? If there were multiple outcomes, was that taken into account for the statistical analysis?	
12. Clinical importance was reported? ☐ Yes ☐ No ☐ Not addressed	What was the clinical importance of the results? Were differences between groups clinically meaningful? (if applicable)	
13. Drop-outs were reported? ☐ Yes ☐ No ☐ not applicable (e.g. cross-sectional design)	Did any participants drop out from the study? Why? (Were reasons given and were drop-outs handled appropriately?)	
DATA VARIABILITY 14. Does the study provide estimates of the random variability in the data for the main outcomes? (Downs and Black, 1998) ☐ Yes ☐ No	In non-normally distributed data the inter-quartile range of results should be reported. In normally distributed data the standard error, standard deviation or confidence intervals should be reported. If the distribution of the data is not described, it must be assumed that the estimates used were appropriate and the question should be answered yes.	
CONCLUSIONS AND IMPLICATIONS 15. Conclusions were appropriate given study methods and results ☐ Yes ☐ No	What did the study conclude? What are the implications of these results for practice? What were the main limitations or biases in the study?	
Remarks		
Total score		

TOTAL: Maximal 14 points for cross-sectional studies and 15 points for prospective studies

11. Acknowledgement

First, I want to thank Prof. Kim Humphreys and Dr. Brigitte Wirth for giving me the opportunity to do the project with them. A special "thank you" goes to Brigitte who was so patient with my schedule concerning my other liabilities in the study program and at work. Furthermore, I want to thank her for taking over the submission process. I also thank the librarian Martina Gosteli for conducting the systematic literature search and Eling de Bruin for his advice on the review protocol. I want to address another thanks to Sandra Rosser for helping with the quality assessment.

12. Lebenslauf

Name, Vorname:	Potthoff, Tobias
Geschlecht:	männlich
Geburtsdatum:	1. April 1986
Nationalität:	Schweiz/Deutsch

Ausbildung:

09.2015 – heute	**Master of Chiropractic Medicine** Universität Zürich, Schweiz
09.2011 – 08.2015	**Bachelor of Medicine, Humanmedizin** Universität Zürich, Schweiz
09.2009 – 12.2011	**Master of Science in Biologie, Teilgebiet Anthropologie,** Universität Zürich, Schweiz Master-Thesis: Functional Morphology of the Talus and Calcaneus in Primates.
10.2006 – 09.2009	**Bachelor of Science in Biologie** Leibniz Universität Hannover, Deutschland Bachelor-Thesis: Experimental study on the spontaneous use of visual *vs.* spatial cues in a foraging task in the Goodman's mouse lemur (*Microcebus lehilahytsara*).
08.1996 – 06.2005	**Ceciliengymnasium Bielefeld,** Deutschland Abitur (LK: Latein und Biologie)
08.1992– 07.1996	**Klosterschule Bielefeld**, Städtische Grundschule, Deutschland

13. Erklärung über die Masterarbeit

Ich erkläre ausdrücklich, dass es sich bei der von mir im Rahmen des Studiengangs

«Master of Chiropractic Medicine»

eingereichten schriftlichen Arbeit mit dem Titel

«A systematic review on quantifiable physical risk factors for non-specific adolescent low back pain»

um eine von mir selbst und ohne unerlaubte Beihilfe sowie *in eigenen Worten* verfasste Masterarbeit* handelt.

Ich bestätige überdies, dass die Arbeit als Ganzes oder in Teilen weder bereits einmal zur Abgeltung anderer Studienleistungen an der Universität Zürich oder an einer anderen Universität oder Ausbildungseinrichtung eingereicht worden ist.

Verwendung von Quellen

Ich erkläre ausdrücklich, dass ich *sämtliche* in der oben genannten Arbeit enthaltenen Bezüge auf fremde Quellen (einschliesslich Tabellen, Grafiken u. Ä.) als solche kenntlich gemacht habe. Insbesondere bestätige ich, dass ich *ausnahmslos* und nach bestem Wissen sowohl bei wörtlich übernommenen Aussagen (Zitaten) als auch bei in eigenen Worten wiedergegebenen Aussagen anderer Autorinnen oder Autoren (Paraphrasen) die Urheberschaft angegeben habe.

Sanktionen

Ich nehme zur Kenntnis, dass Arbeiten, welche die Grundsätze der Selbstständigkeitserklärung verletzen – insbesondere solche, die Zitate oder Paraphrasen ohne Herkunftsangaben enthalten –, als Plagiat betrachtet werden und die entsprechenden rechtlichen und disziplinarischen Konsequenzen nach sich ziehen können (gemäss §§ 7ff der Disziplinarordnung der Universität Zürich sowie §§ 51ff der Rahmenverordnung für das Studium in den Bachelor- und Master-Studiengängen an der Medizinischen Fakultät der Universität Zürich).

Ich bestätige mit meiner Unterschrift die Richtigkeit dieser Angaben.

Datum:

Name: Potthoff Vorname: Tobias

Unterschrift:………………………………………..

* Falls die Masterarbeit eine Publikation enthält, bei der ich Erst- oder Koautor/-in bin, wird meine eigene Arbeitsleistung im Begleittext detailliert und strukturiert beschrieben.